PB80-179831

Continuing Analysis of Multipoint Rollback as Applied to Copper Smelters in the State of Arizona

SRI International
Menlo Park, CA

Prepared for

Environmental Protection Agency
San Francisco, CA

Mar 80

U.S. Department of Commerce
National Technical Information Service
NTIS.

EPA 909/9-80-001

PB80-179831

CONTINUING ANALYSIS OF MULTIPOINT ROLLBACK AS APPLIED TO COPPER SMELTERS IN THE STATE OF ARIZONA

Final Report

March 1980

By: Richard H. Thuillier, Senior Research Meteorologist
Atmospheric Science Center

Harold S. Javitz, Senior Statistician
Statistical Analysis Department

Prepared for:

U.S. Environmental Protection Agency, Region IX
Air and Hazardous Materials Division
215 Fremont Street
San Francisco, California 94105

Attn: Larry Bowerman

and

U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Attn: John R. Busik (EN-341)
Steve Hitte (EN-341)
Edward McLean (PM-214-C)

Contract 68-01-4137, Task 16

SRI Project 5828

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200
Cable: SRI INTL MPK
TWX: 910-373-1246

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA 909/9-80-001	2.	3. Recipient's Accession No. PB 80 179831
4. Title and Subtitle: Continuing Analysis of Multipoint Rollback as Applied to Copper Smelters in the State of Arizona. Final report			5. Report Date: March 1980 6.
7. Author(s): Richard H. Thuillier, Harold S. Javitz			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address: US Environmental Protection Agency, Region IX, Air and Hazardous Materials Division, 215 Fremont St., San Francisco, CA 94105			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

On 4 January 1978, the U.S. Environmental Protection Agency (EPA) promulgated a final rule for the control of sulfur oxide (SO_x) emissions at existing nonferrous smelters in the State of Arizona, imposing a maximum emission limitation for each smelter as a 6-hour running mean. Emission limits, determined from a 1973-74 data base, were set by proportionally "rolling back" the 24-hourly average smelter emissions, estimated by sulfur balance or other methods, for the day on which the maximum 3-hour-average ambient concentration of sulfur dioxide was observed. In response to the EPA rule, the State of Arizona has proposed an alternative approach to calculating copper smelter emission limits based on a statistical model. This new approach is known as "multipoint rollback" and is based upon rollback of the entire distribution of emissions at the smelter. EPA's Region IX Office determined the need for technical assistance in evaluating Arizona's proposed method, and contracted with SRI International (SRI) for an objective evaluation.

17. Document Analysis a. Descriptors

Arizona
Air pollution control
Emissions
Statistical methods

b. Identifiers/Open-Ended Terms

Copper smelters
Stationary sources
AZ Air pollution implementation plan

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

SRI International

EPA 909/9-80-001

CONTINUING ANALYSIS OF MULTIPOINT ROLLBACK AS APPLIED TO COPPER SMELTERS IN THE STATE OF ARIZONA

Final Report

March 1980

By: Richard H. Thuillier, Senior Research Meteorologist
Atmospheric Science Center

Harold S. Javitz, Senior Statistician
Statistical Analysis Department

Prepared for:

U.S. Environmental Protection Agency, Region IX
Air and Hazardous Materials Division
215 Fremont Street
San Francisco, California 94105

Attn: Larry Bowerman

and

U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Attn: John R. Busik (EN-341)
Steve Hitte (EN-341)
Edward McLean (PM-214-C)

Contract 68-01-4137, Task 16

SRI Project 5828

Approved:

Warren B. Johnson, Director
Atmospheric Science Center

Earle D. Jones, Executive Director
Advanced Development Division

SRI International

This report has been reviewed by SRI International and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

CONTENTS

I	INTRODUCTION	1
II	CONCLUSIONS	5
III	REVIEW CHRONOLOGY	9
IV	SUMMARY OF COMMENTS GENERATED THROUGH DOCUMENT REVIEW	11
	A. Derivation of the Multipoint Rollback Method	11
	B. Computation of the Rollback Factor	15
	C. Methods for Counting Violations of 3-hour Average Emissions Limits	18
	D. Methods for Counting Violations of Annual Average Emissions Limits	21
	E. Treatment of Fugitive Emissions	22
REFERENCES		25
APPENDIX--IMPLEMENTATION OF A GENERAL METHOD FOR COUNTING VIOLATIONS OF EMISSIONS LIMITS		27
METRIC CONVERSION TABLE		39

I INTRODUCTION

On 4 January 1978, the U.S. Environmental Protection Agency (EPA) promulgated a final rule for the control of sulfur oxide (SO_x) emissions at existing nonferrous smelters in the State of Arizona, imposing a maximum emission limitation for each smelter as a 6-hour running mean. Emission limits, determined from a 1973-74 data base, were set by proportionally "rolling back" the 24-hourly average smelter emissions, estimated by sulfur balance or other methods, for the day on which the maximum 3-hour-average ambient concentration of sulfur dioxide was observed. The EPA rule is to be enforced by continuous in-stack monitoring of sulfur dioxide (SO_2) concentration and flow rate.

In response to the EPA rule, the State of Arizona has proposed an alternative approach to calculating copper smelter emission limits based on a statistical model. The Arizona Department of Health Services commissioned the University of Arizona (U. of A.) to review the proposed approach, and this review resulted in yet another approach for calculating emission limits. This new approach is known as "multipoint rollback" and is based upon rollback of the entire distribution of emissions at the smelter. Multipoint rollback is described in a paper by the University of Arizona (Moyers and Peterson,1978), which favors this approach over the proportional rollback approach of EPA. EPA's Region IX Office, which has ultimate responsibility for ensuring that the National Ambient Air Quality standards are achieved, has been requested to consider the multipoint rollback approach as a replacement for the current EPA rule.

EPA's Region IX Office determined the need for technical assistance in evaluating Arizona's proposed method, and contracted with SRI International (SRI) for an objective evaluation. Specifically, the EPA needs to know:

- Whether the statistical method is theoretically sound.
- Whether the available data base is adequate for a confident application of the statistical approach.

- Whether the method is enforceable and feasible to implement.
- Whether the statistical method will improve confidence in achieving air quality standards over that associated with the EPA rule.

In the first phase of this work,* SRI reviewed in detail the multipoint rollback method as initially proposed for control of emissions from copper smelters in the State of Arizona. Documents reviewed were "Sulfur Dioxide Emission Limits for Hayden Copper Smelters," by D. B. Morris and L. S. Salmon of Kennecott Copper Corporation; "A Review of Multi-Point Rollback: A Method for Establishing Ultimate Emissions Limitations for Copper Smelters in Arizona," by J. L. Moyers and T. W. Peterson of the University of Arizona; "Technical Support Document: Final Regulations for Control of Sulfur Dioxide Emissions from Arizona Copper Smelters," by EPA Region IX; and "First and Second Annual Reports on Arizona Copper Smelter Pollution Control Technology," by C. Billings of the Arizona Department of Health Services. Personal interviews were also conducted with Dr. Norman Grib and Mr. Larry Bowerman of EPA, Region IX, and with Dr. Thomas Peterson and Dr. Jarvis Moyers of the University of Arizona. At the conclusion of this phase, SRI issued a final task report (Thuillier and Javitz, 1979) entitled: "Theoretical and Empirical Evaluation of Multipoint Rollback as Applied to Smelters in the Hayden Arizona Area."

In view of criticisms developed through the SRI review as well as those generated by EPA Region IX, further work was done by the State of Arizona and the University of Arizona to render the multipoint rollback method suitable for submittal as a State Implementation Plan (SIP) revision. SRI was again retained† to review the ongoing process of developing the method and the final documentation produced, which was submitted to EPA as a SIP revision on 20 September 1979. Documents reviewed were:

---

*Contract 68-01-4137, Task 13.

†Contract 68-01-4137, Task 16.

- "Notice of Proposed Rulemaking," by the State of Arizona.
- "Technical Summary," in various stages of development, by the University of Arizona.
- "Statistical Emissions Limits Method," by Phelps Dodge, Morenci Branch, May 1979.
- "Ultimate Sulfur Dioxide Emission Limits for Arizona Copper Smelters," by the State of Arizona, September 1979.
- "Effect of Measurement Errors on Emission Limits," by Kennecott Copper Corporation, August 1979.
- "State Implementation Plan Determination of 'Good Engineering Practice' Stack Height," by the State of Arizona, September 1979.
- Minutes of Arizona Department of Health Services Hearing on ASARCO's 1000-ft Stack, August 1979.
- "A Wind Tunnel Investigation of Good Engineering Practice (GEP) Stack Height at the ASARCO Smelter, Hayden, Arizona," by North American Weather Consultants, July 1979.
- "Evaluation of 'Good Engineering Practice' Stack Height at the ASARCO Smelter, Hayden, Arizona--A Physical Modeling Study," by Colorado State University, July 1979.

II CONCLUSIONS

Based on SRI's original investigation under Task 13 (Thuillier and Javitz, 1979), we conclude that the statistical multipoint rollback method is theoretically sound as a method for ensuring an expected or average frequency of violation of ambient air-quality standards for sulfur dioxide (SO_2). It is important to note that in the case of SO_2, the current definition of standards violation is based on an absolute frequency of violation in any given year rather than an expected or average frequency.

In SRI's original investigation, we concluded that the multipoint rollback approach, while theoretically sound, suffered from inadequacies in the available data bases and in their application at the time the method was first proposed and demonstrated. Specifically, inadequacies were associated with the statistical uncertainty inherent in the use of a single year of data; the lack of data for applying the method to non-Hayden smelters; contamination of the emissions data set by the application of supplemental control (SCS); and contamination of the air quality data set by the effect of fugitive emissions to which the method does not apply.

Subsequent to SRI's Task 13 review, a number of improvements were made in the application of data bases to the implementation of the multipoint rollback approach. Specifically:

- Use of an expected value of the rollback factor based on available, though size limited, air quality data samples reduces the uncertainty in the rollback factor value, and somewhat obviates the need for a multiyear data sample.
- Generation of emissions profiles for non-Hayden smelters through application of conservative statistical and analytical reasoning renders the multipoint rollback approach applicable to all smelters. While uncertainties are greater in the case of estimated (rather than measured) emissions profiles, the use of conservative assumptions for parameters such as the shape factor biases such uncertainty in favor of air quality protection.

Preceding page blank

- Use of data sets for time periods free of SCS contamination eliminates uncertainty.
- The problem of fugitive emissions was addressed directly* in the case of the Hayden smelters and indirectly in the case of the non-Hayden smelters.

Since a regulatory approach is only as good as the approach to its implementation and enforcement, it is gratifying to note that considerable effort was expended in developing language in the regulations that provides for both the careful identification of violations and a reasonable administrative burden in accounting for violations. The combination of in-stack monitoring with a precisely defined statistical approach to identifying violations is, we find, a feasible, enforceable, and equitable approach to the control of stack-related emissions from Arizona smelters.

With regard to the effectiveness of the method in achieving air quality standards, several observations may be made:

- Because of a difference in definition of the allowable frequency of standards violation, the multipoint rollback approach can not be compared directly with the single-point rollback approach of EPA for efficiency in achieving standards.
- The EPA approach attempts to limit the maximum possible ambient concentration to that of the standard; thus maximum emissions, must be limited to those compatible with worst case meteorological conditions. This approach is logical under the current allowance of no-more-than-one violation in any given year, but highly inequitable in requiring the smelters to limit emissions even under meteorological conditions unlikely to cause violations of the air quality standards. In spite of its stringency, the EPA method cannot be assumed to guard absolutely against violations of the air quality standards in view of uncertainty in the definition of the worst-case conditions.
- The multipoint rollback approach seeks to limit violation of air quality standards to a statistically probable occurrence of once-per-year. This approach considers the joint probability of emission rates and meteorological conditions leading to a

---

*In the case of non-Hayden smelters, the rollback factor is based on ambient data, which reflect the influence of fugitive emissions. Fugitives are therefore treated directly insofar as they are related to controlled stack emissions. In the case of the Hayden smelters, the rollback factor is based on an adjusted standards violation frequency, which accounts statistically for data determined meteorologically to be related to fugitive emissions.

violation and specifies an allowable distribution of emission rates rather than a single emissions-limit value. The multipoint rollback method is more equitable than the EPA method, in that it seeks to achieve the standard with greater flexibility in smelter operations. While the multipoint approach requires a considerable reduction in smelter emissions overall, it allows higher rates of emission than does the EPA approach in view of the estimated probability of resulting violations.

- Both the EPA approach and multipoint rollback operate on the same types of data bases and consequently suffer from the same data-related uncertainties. While both methods operate at the extremes of the associated statistical distributions, the design violation frequency of multipoint rollback is somewhat more stable statistically than the maximum design value in the EPA approach. The statistical framework of the multipoint rollback method also facilitates a more comprehensive evaluation of likely air quality consequences than does EPA's approach.

III REVIEW CHRONOLOGY

Subsequent to SRI's submittal of its final task report under Task 13, the State of Arizona, through the Department of Health Services, proposed rules* outlining an approach to smelter emissions limitations based on multipoint rollback. The proposed rules were supported by a Technical Support Document (TSD) prepared by the University of Arizona.

These initial documents were reviewed by SRI along with a paper entitled, "Statistical Emission Limits Method," by Phelps Dodge, Morenci Branch (Kendall, 1979), which described statistical methodologies for estimating smelter emissions distributions and analyzed the SCS contamination problem at Hayden, Arizona. A series of comments and suggestions were submitted to Region IX on an informal basis: A detailed summary of these comments is provided in Section III-B. Upon development by the State of Arizona of its SIP revision (officially submitted to EPA on 20 September 1979), SRI reviewed the final documentation: "Ultimate Sulfur Dioxide Emission Limits for Arizona Copper Smelters," by the Arizona Department of Health Services (ADHS); Minutes of the ADHS hearing on ASARCO's 1,000-ft stack; Arizona's "State Implementation Plan Determination of "Good Engineering Practice Stack Height;" a report by North American Weather Consultants entitled, "A Wind Tunnel Investigation of Good Engineering Practice (GEP) Stack Height at the ASARCO Smelter, Hayden, Arizona," and a report by Drs. R. L. Petersen and J. E. Cermak of Colorado State University entitled, "Evaluation of 'Good Engineering Practice' Stack Height at the ASARCO Smelter, Hayden, Arizona--A Physical Modeling Study." SRI's review of these final documents in light of the comments and suggestions summarized in Section IV is the basis for the conclusions and recommendations appearing in Section II.

---

*Arizona Department of Health Services, July 10, 1979.

Preceding page blank

IV SUMMARY OF COMMENTS GENERATED THROUGH DOCUMENT REVIEW

A. Derivation of the Multipoint Rollback Method

While it is our position that the multipoint rollback concept is theoretically sound, we have never been completely satisfied with the mathematical derivation that appears throughout the documentation. SRI has formulated a very simple derivation that extends the method to moving average concentrations and minimizes the assumptions underlying the method. The SRI derivation is outlined as follows:

Envision a continuous stream (time series) of emissions from the copper smelter. Let E_t denote this time series from time t back into the recent past (say up to 7 days). Similarly, let D_t denote the continuous time series of meteorological conditions from time t back into the recent past. By C_t, denote the average observed concentration over either: the hour ending at time t; the 3-hour interval ending at time t, or the 24-hour interval ending at time t. Finally let T be an appropriate index set for t. Thus, if C_t denotes an hourly average or a 3- or 24-hour overlapping concentration average, then T indexes 8760 t values per calendar year; if C_t denotes a 3-hour nonoverlapping concentration average, then T indexes 2920 t values per year; if C_t denotes a nonoverlapping 24-hour average, then T indexes 365 t values per year.

Since C_t depends upon E_t and D_t, we may formally express this functional relationship as

$$C_t = g\ (E_t,\ D_t) \qquad t \varepsilon T$$

The function g may be very complicated. The fundamental assumption of the multipoint rollback method is that if all emissions E_t had been reduced by a factor r, then C_t would have been reduced (at least) by that same factor. Notationally,

Preceding page blank

$$g\ (E_t/r,\ D_t) = \frac{1}{r}\ g\ (E_t,\ D_t) = \frac{1}{r}\ C_t \quad t\varepsilon T \quad .$$

For SO_2, and a variety of other pollutants, this is a very reasonable assumption.

Up to this point, we have been dealing with a past time period for which concentrations C_t were observed, corresponding to actual emissions E_t and dispersion conditions D_t. We have assumed that if E_t had been reduced by a factor r then C_t would also have been reduced by this factor. Now we consider a future time period. Let the future concentrations, emissions, and dispersion conditions be denoted C_t^*, E_t^*, and D_t^*.

The multipoint rollback method is based on the following observation: If E_t^* and D_t^* follow the same joint probability distribution as E_t/r and D_t, then C_t^* will follow the same probability distribution as C_t/r. Notationally, if

$$E_t^*,\ D_t^* \sim E_t/r,\ D_t$$

then

$$C_t^* \sim C_t/r \quad .$$

Obviously, if the observed concentrations C_t exceed the air quality standards, then a sufficiently large rollback factor r should be chosen so that C_t^* is in compliance.

Before considering how the rollback factor should be computed, we will consider certain ramifications of our derivation. First, we have never assumed that emissions and dispersion conditions are independent. In fact, if the emissions E_t and dispersion conditions D_t were dependent in the time periods used to compute the reduction factor r, the same dependency would have to be maintained in the future time period between E_t^* and D_t^* to ensure that C_t^* followed the same distribution as C_t/r. Thus, if SCS was in effect when r was computed, an adequate reduction in future concentrations would require the maintenance of the SCS.

Secondly, in order for the anticipated reduction in future concentrations to be achieved, it is necessary to assume that future dispersion conditions D_t^* will be at least as good as past dispersion conditions D_t. If the rollback factor r was computed during a time period with unusually good dispersion conditions D_t, then in any subsequent year with poorer dispersion conditions D_t^* and emissions $E_t^* = E_t/r$ the resultant concentrations C_t^* will not follow the same distribution as C_t/r, but instead will be stochastically larger.

Thirdly, the condition that E_t^* follow the same distribution as E_t/r is much stronger than the condition that the marginal distribution of the hourly emission averages in the future year be the same as the marginal distribution of the rolled-back hourly emission averages in the base time period. The condition that E_t^* follow the same distribution as E_t/r implies that the time-variability in E_t^* also matches the time variability in E_t/r. For example, if hourly emissions during the base period followed a cyclic pattern, with an average period (peak to peak) of 10 hours, then it is necessary that the hourly emissions in the future time period exhibit the same average period. If emissions during the base time period were curtailed whenever the hourly emissions exceeded X lb/hr, then it is necessary that an equivalent curtailment be used whenever emissions in the future time period exceed X/r lb/hr. For all practical purposes, the condition that E_t^* have the same distribution as E_t/r requires that there be no substantial differences between the t pairs of time series of E_t^* and E_t/r when plotted against t. That is, a researcher knowledgeable in time series analysis and interpretation would conclude that the same process generated both the $\{E_t/r \quad t \varepsilon T\}$ and $\{E_t^* \quad t \varepsilon T\}$ series.

We now return to the problem of determining the rollback factor r. A rollback factor r affects the underlying statistical distribution of C_t^*, and therefore in order to compute r we must express compliance with the standard in a "statistical" format. Thus, we could require the expected number of exceedences of C_t^* above some upper limit U to be one, or we could require that the probability of three or more exceedences be 5 percent or less, but we cannot require that there be no more than

one exceedence per year. It is difficult to work with probabilistic statements concerning the behavior of the C_t^*, since there is no reason to believe that the C_t^* are independent of one another. Consequently, we shall assume that we are determining r to comply with a standard expressed in terms of a statistical expectation: the expected number of exceedences of C_t^* above the limit U shall equal 1.0. Thus we seek a reduction factor r such that

$$E\left\{ I\ (C_1^* > U) + I\ (C_2^* > U) + \ldots + I\ (C_n^* > U) \right\} = 1.0 \quad ,$$

where

$$I\ (C_i^* > U) = \begin{cases} 0 \text{ if } C_i^* \leq U \\ 1 \text{ if } C_i^* > U \end{cases}$$

n = number of future observations in a calendar year (8760, 2920, ...).

By the linearity of the expectation operator, and the fact that expectation of an indicator variable is a probability, this condition reduces to:

$$\sum_{i=1}^{n} P\left\{ C_i^* > U \right\} = 1.0 \quad .$$

Since C_t^* is assumed to follow the same distribution as C_t/r, the condition further reduces to

$$\sum_{i=1}^{n} P\left\{ C_i > r\,U \right\} = 1.0 \quad .$$

If the C_i were identically distributed, the above condition would be equivalent to the statement that r U is the upper 1/nth percentile of the distribution of C_t:

$$P\left\{ C_t > r\,U \right\} = 1/n \quad .$$

In this case, r may be estimated from the observed 1/nth percentile of the distribution of C_t. That is, the estimate of r is

$$\hat{r} = (\text{observed } 1/n\text{th percentile of the } C_t \text{ distribution})/U.$$

The estimate $\hat{r}$ may be improved by fitting a distribution (e.g., a gamma distribution) to the tail of the C_t distribution and using the computed 1/nth percentile of the C_t distribution in place of the observed 1/nth percentile. Even if the C_i are not identically distributed, the estimate $\hat{r}$ derived above will often be a good estimate of r.

Two final cautionary notes are in order. First, the $\hat{r}$ is only an estimate of r, and may be too large or too small. The accuracy with which $\hat{r}$ estimates r will improve as the number of years of data used in computing the distribution of C_t increases. Secondly, we caution against using data bases that are not balanced over the full year without employing more sophisticated estimation techniques. Thus if the data base for C_t consisted of two full years of data, and one half-year of data (from January to June), the estimation technique described here should only be used on the two full years of data, unless a weighting procedure is employed.

B. Computation of the Rollback Factor

Both the EPA approach and the multipoint rollback approach employ a rollback factor (R), which may be defined as the ratio of the concentration specified by the ambient air-quality standard to a design value in the current distribution of concentrations. In the EPA approach,

$$R = \frac{\left[SO_2\right]_{std}}{\left[SO_2\right]_{max}} \quad , \qquad (1)$$

where

$\left[SO_2\right]_{std}$ is the ambient SO_2 concentration specified by the standard

and

$\left[SO_2\right]_{max}$ is the design value taken as the highest observed concentration of SO_2 in the available data set.

In the multipoint rollback approach,

$$R = \frac{\left[SO_2\right]_{std}}{\left[SO_2\right]_p} \quad , \tag{2}$$

where $\left[SO_2\right]_p$ is a percentile value that is associated with a once per-year frequency of occurrence in the current concentration distribution.

The rollback factor is applied as a reduction factor to some parameter (E) of the emissions distribution for a source, on the premise that reduction of E from its current value by the factor R will ensure the maintenance of a desired frequency for violation of the standard. The desired relationship of the allowable value of E (E_{max}) to its current value (E_o) may be expressed as

$$E_{max} \leq E_o \cdot R \quad . \tag{3}$$

In the EPA approach, E_o is taken as the emission rate occurring at the same time as the measurement of $\left[SO_2\right]_{max}$. In the multipoint rollback approach, E_o represents the existing and E_{max} the allowable distribution of emissions.

Computation of the rollback factor for multipoint rollback has undergone considerable evolution between the original technical presentations (Moyers and Peterson, 1978) and the promulgation of the final

technical support statement by the University of Arizona (Moyers and Peterson, 1979). Initially, the design air-quality value was the same as that used by EPA, namely the highest observed concentration in a one-year data set. Subsequently, an expected value was obtained by fitting observed data with a distribution function, from which a percentile is obtained representing an expected recurrence frequency of once per year. Specifically, the University of Arizona investigators have computed the rollback factor by:

- Subdividing the set of moving 3-hour concentration averages into 3 subsets
- Computing the 1/2920th percentile for each subset
- Choosing the maximum of the 3 percentiles
- Dividing the maximum into the concentration standard.

The expected-value approach is an improvement over the original approach, which is based on the observed maximum value, since it reduces the probability of basing the rollback on an unrepresentative air-quality value.

While air-quality standards exist for annual, 24-hour, and 3-hour averaging times in the case of SO_2, the 3-hour average has been determined as the controlling standard in the case of the Arizona smelters. That is, conditions are such that meeting the 3-hour standard will provide reasonable assurance of meeting the standards for the other averaging times as well. In the case of the 3-hour SO_2 standard, the value of 1/2920 (equivalent to nonoverlapping 3-hour averages) was chosen as representative of the expected, once-per-year value for discrete 3-hour averages upon which determination of violations of the standard is based.

We believe that this method for calculating the 3-hour rollback may yield too small a rollback factor. The reasoning is most easily explained by using a percentile larger than the 1/2920th percentile. For example, suppose that we are interested in establishing a rollback factor just large enough so that there would be 4 or fewer exceedences of the standard every year. Following the U. of A. methodology, the 4/2920th percentile of three subsets of the data is determined. Let X equal

the maximum of the three 4/2920th percentiles. It could easily occur that the first subset has 3 concentration averages in excess of X, the second subset has 4 concentration averages in excess of X, and the third subset has 2 concentration averages in excess of X. In total, we have 9 concentrations in excess of X, a number that exceeds the standard even after a rollback. If none of the 9 concentration averages contains any common hour, then nine violations of the air quality standards occur even after a rollback, clearly short of the goal of determining a rollback factor for which only 4 exceedences would occur. Of course, some of the 9 concentration averages might overlap in time, in which case the violations of the air quality standards number less than 9. It is unlikely however that they all would occur in only four 3-hour time periods. Thus, the rollback factor computed from X is too small.

The problem in this case is that we cannot neglect the contribution of the two subsets with 4/2920th percentiles below X. When we are considering the 1/2920th percentiles, two subsets do not contribute concentrations above X = max of 1/2920th percentiles, but they do contribute some probability of an exceedence. We speculate that the U. of A. method would result in about 2 exceedences per year when the 1/2920th percentiles are close to one another, but a Monte Carlo simulation would be necessary to ascertain the correctness of this assertion.

C. Methods for Counting Violations of 3-Hour Average Emissions Limits

In its proposed regulations of 10 July 1979, the State of Arizona presented a method by which 3-hour average concentrations in excess of specified cumulative occurrence limits would be counted as violations. One of the concerns in formulating the method was that a single emissions average in excess of a specified cumulative limit might contribute to more than one violation; that is, that the source might be placed in double jeopardy.

The approach proposed by the State of Arizona sought to avoid this by specifying that hourly emissions used in a 3-hour emissions average in violation of an occurrence limit could not be considered in assigning

subsequent violations of the same limit. This method took care of the double jeopardy problem for discrete 3-hour averages as well as for overlapping averages. Additionally, the method specified a running 365-day compliance period, so that 3-hour averages more than one year old are also excluded from further consideration.

The problem that SRI identified with this method was that data were being discarded at both ends of the compliance period, resulting in an unnecessarily large data loss. As an example, consider the case where n 3-hour averages in excess of a cumulative limit E are allowed by the regulation. Assume that excess number 1 occurred on 1 January and excess n + 1 occurred on 31 December. A violation would be issued under the regulation and 3-hour average n + 1 would be discarded. On the next day, however, the excess number 1 would also be discarded, because of "old age," resulting in the immediate loss of two excesses from the data set. The consequence is that two additional excesses would then be required to assign one additional violation. This seemed to constitute excessive leniency.

As an alternative, SRI proposed a general method based on the principle of first-in/first-out, which is embodied in two rules that may be stated as follows:

(1) A 3-hour average is "counted against" any cumulative emission limits that it exceeds unless it is more than 12 months old or it has been "discarded" in accordance with Rule 2.

(2) If a 3-hour average ending at hour t causes one or more cumulative limits to be exceeded, then

- For each exceeded cumulative limit, the earliest 3-hour average currently counted against the limit is discarded, and
- A violation is issued, provided that for at least one of the exceeded cumulative limits (say associated with an emission level E), neither the 3-hour average ending at time t minus 1 nor the average ending at time t minus 2 resulted in the issuance of a violation of an emission level greater than or equal to E.

An example of application for the SRI approach is provided as an Appendix. Under the SRI rules, only the 1 January excess in the example above would be discarded, and only one additional excess would be required for

one additional violation. SRI Rule 2 precludes double jeopardy arising from multiple consideration of 1-hour averages in overlapping 3-hour excesses.

In the final regulations promulgated in September 1979, a revised method was included that essentially eliminated the discarding process except for data more than one year old. An exception is that hourly averages used to compute a violation of a cumulative occurrence limit of 3 or less may be used only once in determining compliance with that same limit. Additional features of the promulgated rules are the use of once-per-month rather than one-per-day accountability and the provision that multiple excesses of a cumulative limit within a single day be counted as a single violation. The latter provision arises from the judicial practice of assessing fines for violation of air quality regulations on a per-day-of-violation basis.

SRI is satisfied that the promulgated regulations represent a reasonable approach to assignment of violations for excesses of cumulative 3-hour emissions limits. We have some concern, however, for the interpretation that might be given to the provision regarding cumulative occurrence limits of 3 or less. If this provision excludes only those excesses over and above those that constitute the limit, such as excess number 4 where 3 are allowed, we have no problem. The language would seem, however, to be open to an unfortunate interpretation that would discard all 4 excesses in the example just cited and thus would require 4 new excesses to yield a single new violation of the limit.

If an excess occurs that includes hours from two days (e.g., 11 pm, 12 pm, and 1 am), and this excess results in the violation of a cumulative exceedence limit, it is unclear (from the current wording) against which of the two days the violation would be counted. This matter is important because of the provision that not more than one violation can be issued per day. The day that the 3-hour average is not counted against is vulnerable to an additional violation; the day that the 3-hour average is counted against may have already incurred an earlier violation.

D. Methods for Counting Violations of Annual Average Emissions Limits

In assigning violations for excesses of the annual average emissions limit, the use of a running average leads to the problem of multiple annual average violations assigned on the basis of a single short-term excess of the annual limit. A high rate of emission on a single day, for example, might maintain the running average in excess of the annual limit for a number of days, resulting in a chain of violations associated with the single high-emissions event. This problem was addressed in the promulgated rules by the use of a once-per-month period of accountability for annual average violations, thus allowing sufficient time for the effect of an extreme event to subside.

Region IX asked SRI to suggest alternative regulatory language that might be used to provide for daily accountability. We provide the following language, which may be inserted on Page VI-15, Line 24 through Page VI-17, Line 13 of the final SIP revision. (Paragraphs 3(a) and 3(b) address the problem of daily accountability for the mean emissions; Paragraphs 3(c) through 3(h) solve the problems that we noted earlier for the 3-hour averages.)

"3. Compliance with the cumulative occurrence and emission limits contained in Paragraph 1 for all compliance periods subsequent to the initial 365-day compliance period specified in Paragraph 2 shall be determined as follows:

a. Annual average emissions shall be calculated at the end of each day.

b. For purposes of this paragraph, an annual emissions average in excess of the allowable annual average emissions limit in Paragraph 1 will be considered to violate that allowable annual average emissions limit if:

i. The annual average is larger than the annual average computed in the preceding day; or

ii. The annual average computed in the 10 preceding days all exceed the allowable annual average emissions limit.

c. Three-hour emissions averages shall be calculated at the end of each clock hour by averaging the hourly emissions for the preceding three consecutive hours

whenever each such hour was measured in accordance with the requirements contained in Paragraph 4.

d. For purposes of this paragraph, a three-hour emissions average in excess of an emission level (E) will be considered to violate the associated cumulative occurrence limit (n) listed in Paragraph 1 if the number of all three-hour emissions averages measured during the compliance period in excess of that emission level exceeds the cumulative occurrence limit associated with the emissions level.

e. For purposes of determining compliance with this paragraph the compliance period shall consist of the 365 days immediately preceding each day.

f. A three-hour emissions average can only violate the cumulative occurrence limit (n) of an emissions level (E) in the day containing the last hour in the average.

g. Multiple violations of a cumulative occurrence limit in the same day and violations of different cumulative limits in the same day shall constitute a single violation of the requirements of this section.

h. Multiple violations of a cumulative occurrence limit by different three-hour emissions averages containing any common hour shall constitute a single violation of the requirements of this section."

The application of this language as pertains to the annual emissions average is illustrated in Figure 1. In that figure, the allowable annual average emission limit is 10,000 lb/hr.* Hypothetical annual average emissions are plotted, starting with the first day after the initial one-year compliance period. The annual average emission plotted against a day t is the average of all emissions on day t through day t-364; six chargeable violations of the emission limit occur (on days 12, 17, 18, 20, 27, and 28).

E. Treatment of Fugitive Emissions

One serious problem associated with the successful application of multipoint rollback to smelter operations is that the method applies only to emissions for which a detailed statistical distribution can be

---

*A metric conversion table is included at the end of this report.

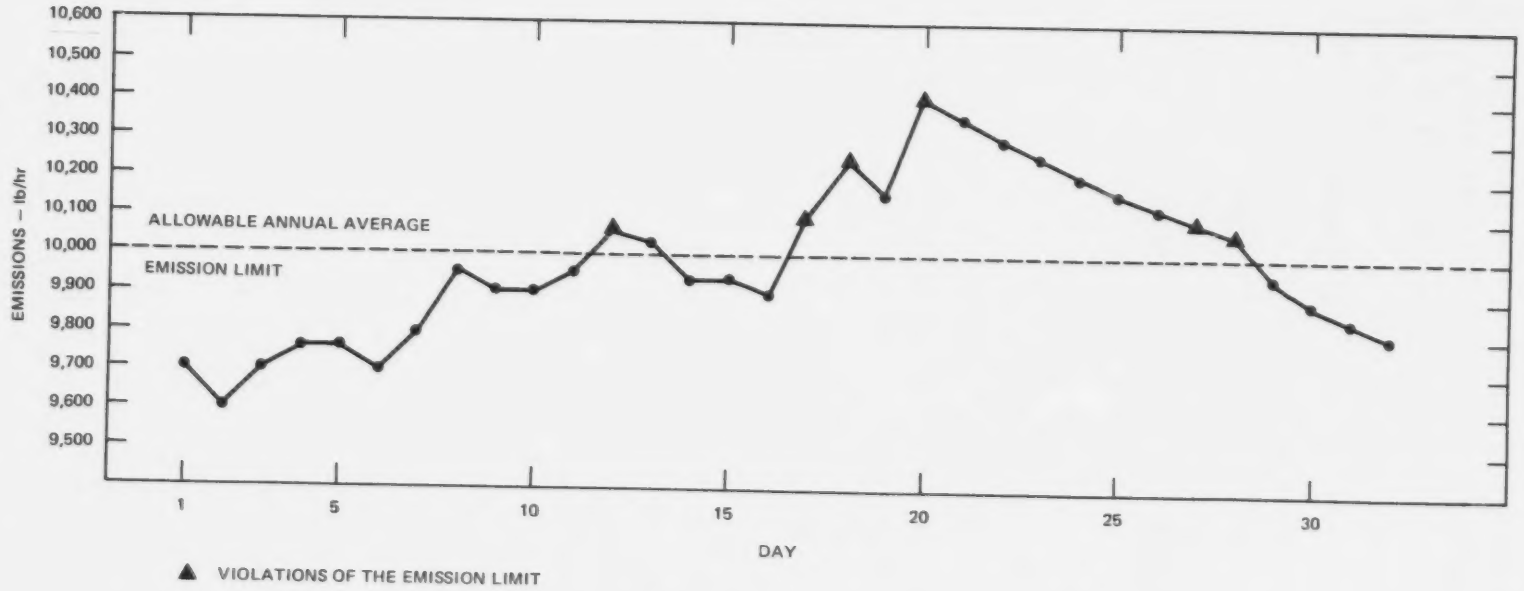

FIGURE 1 A SAMPLE PLOT OF THE ANNUAL AVERAGE EMISSIONS
Plot starts with the first day after the initial one-year compliance period.

obtained. In-stack monitoring provides such statistics for stack emissions, but no such data are available in the case of fugitive emissions. The problem is further complicated by the fact that the statistical distribution of air quality, upon which the rollback is based, is influenced by fugitive as well as stack emissions. If no attempt is made to account for the fugitive influence, the resulting rollback may be overly stringent with respect to stack emissions; but since only stack emissions are controlled by the rollback (except insofar as fugitive and stack emissions are related), the air quality problem caused by fugitive emissions will not be addressed. Where fugitive contributions dominate the air quality statistics, the improvement due to rollback may be of little significance.

The University of Arizona has attempted to address the problem of fugitives (in the case of the Hayden smelters only) by adjusting the rollback factor percentile value from 1/2920 to 1/1022 to reflect a 65 percent frequency of fugitive influence based on meteorological considerations. SRI considers this method to be reasonable, although it somewhat dilutes the reliability of the statistics.

Until such time as the fugitive problem is better defined, the effectiveness of the multipoint rollback approach will continue to be diluted. If fugitive emissions could be quantified and monitored, the multipoint rollback approach would be applicable. If fugitives could be routed through the stack, there would be no problem at all, since the fugitives would be simply a component of stack emissions. Should the fugitives continue to constitute a separate source, subject to a different meteorological dispersion regime than stack emissions, workable approaches will have to be developed to enable separation of the fugitive component from the air quality statistics, and separate applications of multipoint rollback to stack and fugitive problems will be required.

REFERENCES

Kendall, S. B., 1979: "Statistical Emissions Limit Method," Phelps Dodge Corporation, Morenci Branch.

Moyers, J. L. and T. W. Peterson, 1978: "A Review of Multi-point Rollback: A Method for Establishing Ultimate Emissions Limitations for Copper Smelters in Arizona," University of Arizona.

Moyers, J. L. and T. W. Peterson, 1979: "Technical Support Statement--Application of Multipoint Rollback Calculations for Establishing Sulfur Dioxide Emissions Limits for Copper Smelters in Arizona," (14 September).

Thuillier, R. H. and H. L. Javitz, 1979: "Theoretical and Empirical Evaluation of Multipoint Rollback as Applied to Smelters in the Hayden, Arizona, Area," SRI International, Menlo Park, California, Final Report, EPA Contract 68-01-4137, Task 13.

Appendix

IMPLEMENTATION OF A GENERAL METHOD FOR COUNTING
VIOLATIONS OF EMISSIONS LIMITS

The implementation of the general method requires the use of bins, as shown in Figure A-1 for the Kennecott smelter (see p. 6 of the NPR).

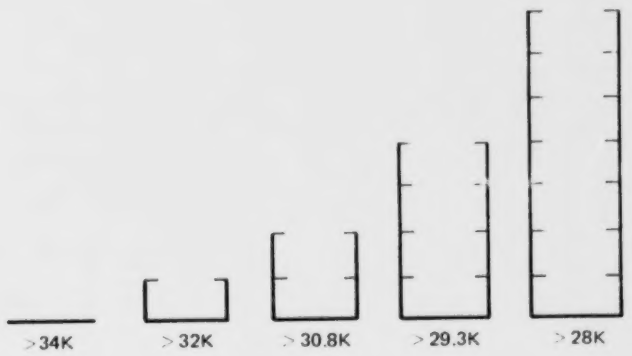

FIGURE A-1

According to the proposed State of Arizona rule for this smelter, 26 bins would be required; we show only the first 5 bins. Each bin can hold the allowable number of 3-hour averages in excess of the emission level labeling the bottom of the bin.

Let X_i denote the 3-hour average emission starting in the ith hour. The smelters are responsible for obtaining X_1, X_2, X_3, ... The X_i are placed into the bins as described below (where for simplicity we assume that there are only 5 bins).

(1) Suppose that X_1 = 26K, X_2 = 25.3K, X_3 = 30.3K. The bins' contents are shown in Figure A-2.

The first two X's are too small to belong to any of these bins and X_3 belongs in two bins.

Preceding page blank

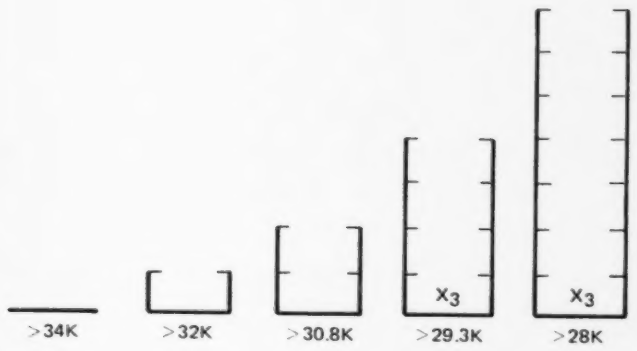

FIGURE A-2

(2) Suppose that X_4 = 29K, X_5 = 31K, X_6 through X_{30} are < 27K, and X_{31} = 31.7K. The bin configuration is now as shown in Figure A-3.

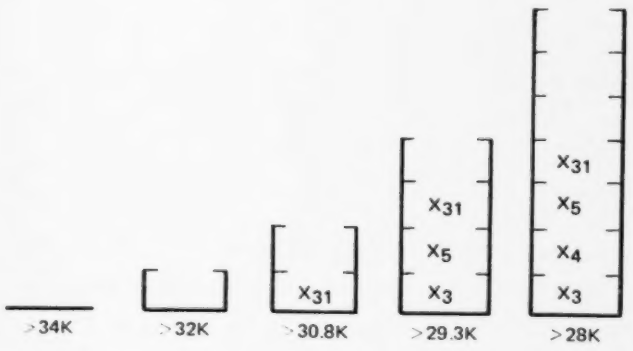

FIGURE A-3

(3) Suppose that X_{32} through X_{50} are < 27.5K, X_{51} = 31.9K and X_{52} = 30.1K. The bin configuration is as shown in Figure A-4.

At this time a violation is issued because the fourth bin has overflowed. After issuing the violation, we push down this stack to obtain Figure A-5.

Only the overflowing stack is pushed down. Each X_{52} is marked with a star because X_{52} resulted in a violation.

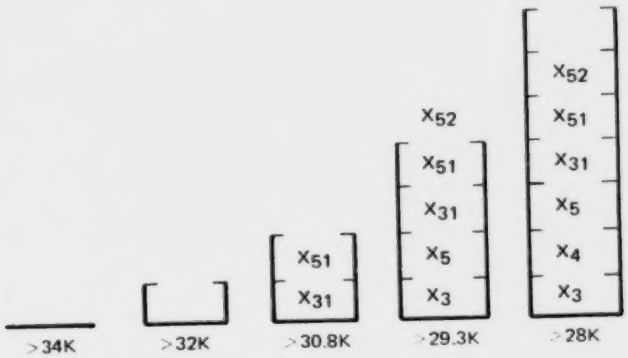

FIGURE A-4

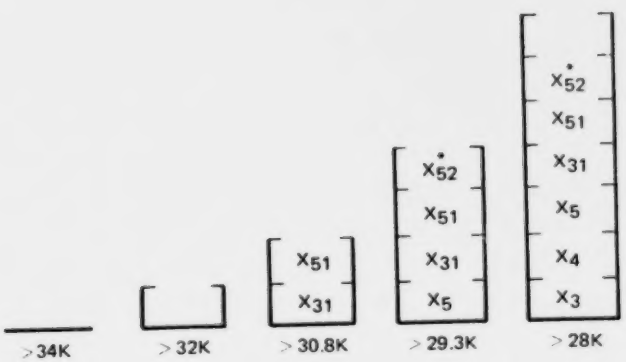

FIGURE A-5

(4) Suppose X_{53} = 30.5. The bin configuration is shown in Figure A-6.

At this time another push-down is required. We recommend that this be done without issuing another violation, because X_{52} (which contains an overlapping hour with X_{53}) resulted in a violation. After pushing down this stack we obtain Figure A-7.

Note that X_{53} is not marked with a star because no violation was issued.

(5) Suppose X_{54} through X_{62} is < 27K, and X_{63} = 29.6K. The bin configuration is shown in Figure A-8.

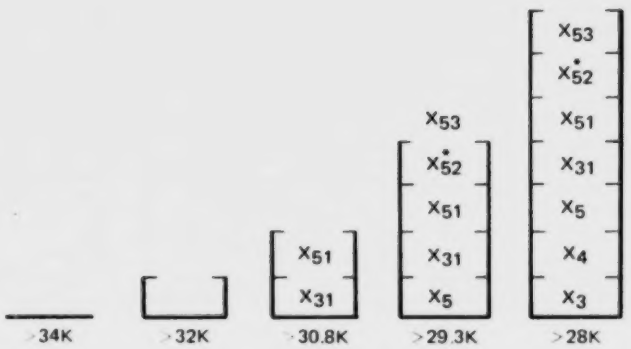

FIGURE A-6

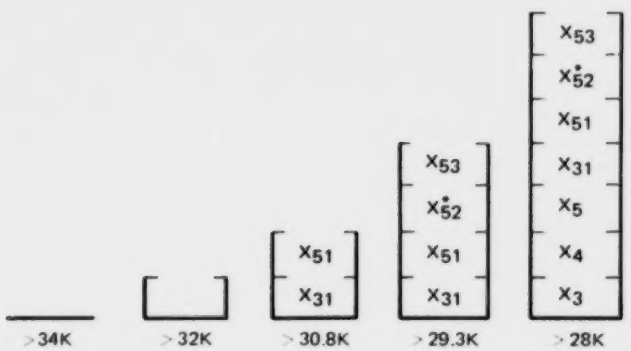

FIGURE A-7

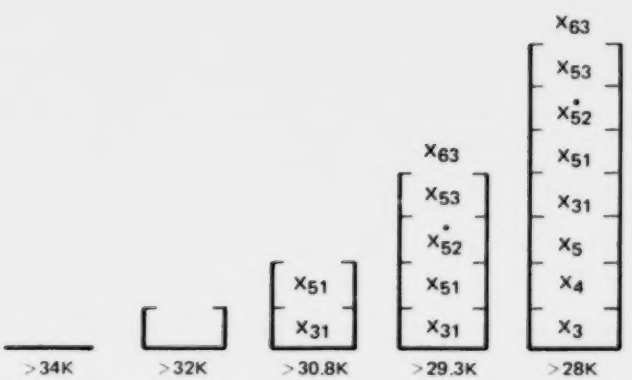

FIGURE A-8

A double push-down (i.e., a push-down of two stacks) is required. We recommend that this be counted as a single violation because we are concerned with the compliance of the entire distribution function. The bin configuration after the double push-down is shown in Figure A-9.

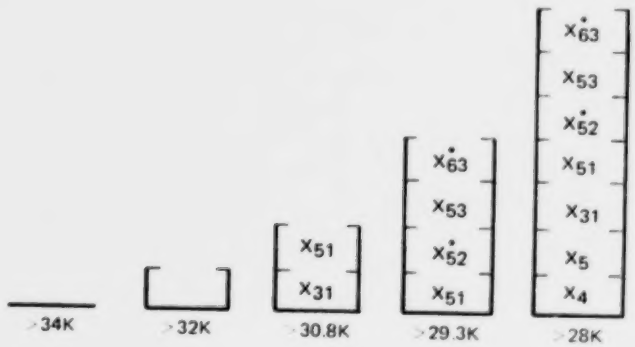

FIGURE A-9

Notice that since a violation was issued, all X_{63}'s are starred.

(6) Suppose $X_{64} = 30.1$. The bin configuration after a double push-down is as shown in Figure A-10.

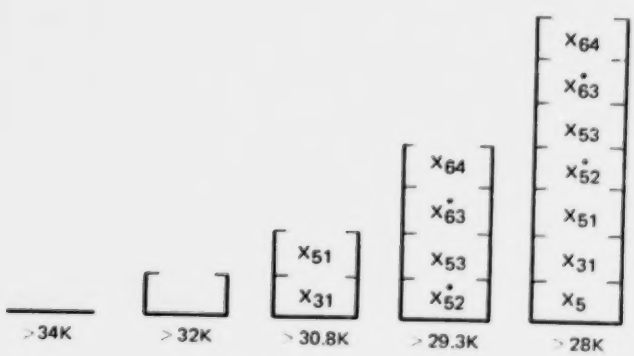

FIGURE A-10

No violation is issued because both of the pushed-down stacks had a starred 3-hr average (X_{63}) that overlapped with the 3-hr average (X_{64}) being pushed down onto the top of the stacks.

(7) Suppose X_{65} = 30.2. After the double push-down the bin configuration is as shown in Figure A-11.

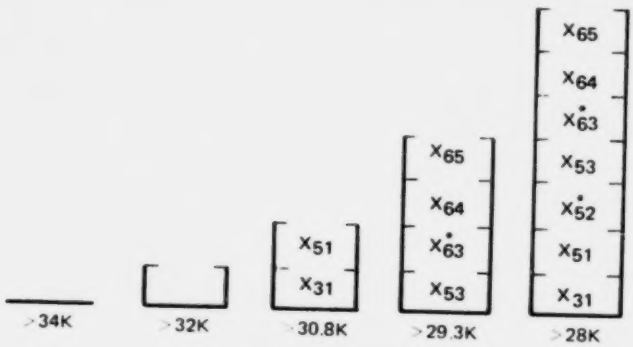

FIGURE A-11

Once again, no violation is issued, because both of the pushed-down stacks had a starred 3-hr average (X_{63}) that overlapped the 3-hr average (X_{65}) being pushed down onto the top of the stack.

(8) Suppose X_{66} = 29.5. After a double push-down the bin configuration is as shown in Figure A-12.

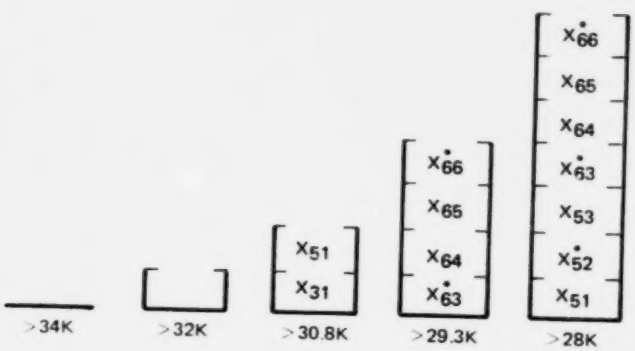

FIGURE A-12

Notice that a violation has been issued (e.g., X_{66} has been starred). Although X_{65} and X_{64} were in the pushed-down stacks, they did not prevent the violation from occurring because they were not starred; X_{63} did not prevent the violation because it does not overlap X_{66}.

(9) Suppose X_{67} = 31.5K. After a triple push-down the bin configuration is as shown in Figure A-13.

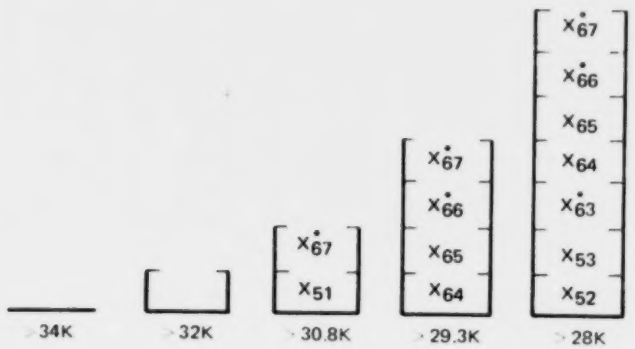

FIGURE A-13

A violation is issued because of the push-down in the bin labeled ">30.8K." All X_{67}'s are starred whenever any one of them results in a violation.

(10) Suppose X_{68} through X_{8808} < 28K. Before X_{8809} can be observed, X_{52} ages beyond 12 months (one year = 8758 3-hr time intervals) and is discarded. The bin configuration is now as shown in Figure A-14.

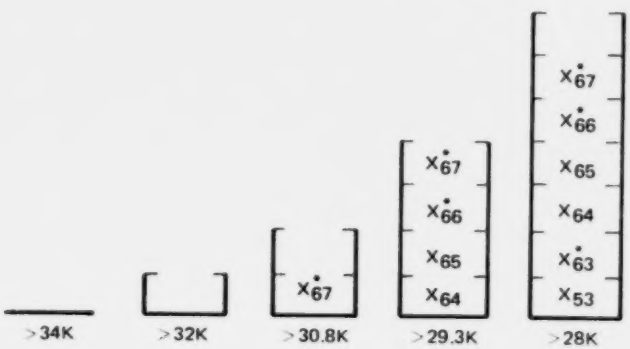

FIGURE A-14

(11) Suppose X_{8809} = 35K. After a double push-down (of the first and fourth bins) and the issuance of a violation, the bin configuration is as shown in Figure A-15.

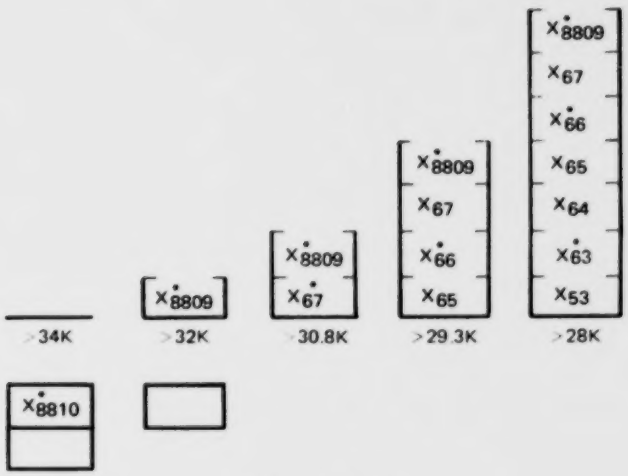

FIGURE A-15

Figure A-15 shows an additional feature of the bin scheme--some "holding tanks" for discarded Xs from the first two bins. We have not shown these holding tanks before, because they were not needed (i.e., nothing was discarded from the first two bins).

(12) Before X_{8810} is observed, X_{53} ages and is discarded. Suppose X_{8810} = 35.2K. After a quadruple push-down the bin configuration is as shown in Figure A-16.

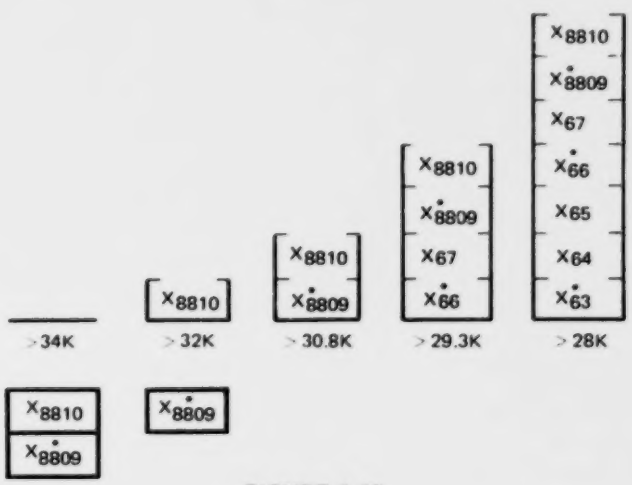

FIGURE A-16

No violation was issued because each of the pushed-down bins had a starred X_{8809} in it or in its holding tank. (The only purpose of the holding tank is to allow us to "remember" if an X that overlaps the one being pushed down has been starred.)

(13) Suppose $X_{8811} < 27K$, and $X_{8812} = 36K$. The bin configuration after a quintuple push-down and the issuance of a violation is shown in Figure A-17.

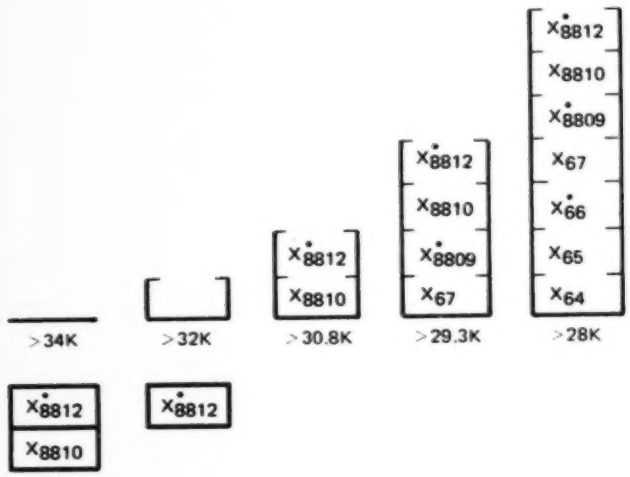

FIGURE A-17

Notice that X_{8809} has fallen out of the bottom of the holding tanks (exactly as if these tanks were a continuation of the bins).